

## Active microwave remote sensing for soil moisture measurement: a field evaluation using ERS-2

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### Abstract:

Active microwave remote sensing observations of backscattering, such as C-band vertically polarized synthetic aperture radar (SAR) observations from the second European remote sensing (ERS-2) satellite, have the potential to measure moisture content in a near-surface layer of soil. However, SAR backscattering observations are highly dependent on topography, soil texture, surface roughness and soil moisture, meaning that soil moisture inversion from single frequency and polarization SAR observations is difficult. In this paper, the potential for measuring near-surface soil moisture with the ERS-2 satellite is explored by comparing model estimates of backscattering with ERS-2 SAR observations. This comparison was made for two ERS-2 overpasses coincident with near-surface soil moisture measurements in a 6 ha catchment using 15-cm time domain reflectometry probes on a 20 m grid. In addition, 1-cm soil moisture data were obtained from a calibrated soil moisture model. Using state-of-the-art theoretical, semi-empirical and empirical backscattering models, it was found that using measured soil moisture and roughness data there were root mean square (RMS) errors from 3.5 to 8.5 dB and  $r^2$  values from 0.00 to 0.25, depending on the backscattering model and degree of filtering. Using model soil moisture in place of measured soil moisture reduced RMS errors slightly (0.5 to 2 dB) but did not improve  $r^2$  values. Likewise, using the first day of ERS-2 backscattering and soil moisture data to solve for RMS surface roughness reduced RMS errors in backscattering for the second day to between 0.9 and 2.8 dB, but did not improve  $r^2$  values. Moreover, RMS differences were as large as 3.7 dB and  $r^2$  values as low as 0.53 between the various backscattering models, even when using the same data as input. These results suggest that more research is required to improve the agreement between backscattering models, and that ERS-2 SAR data may be useful for estimating fields-scale average soil moisture but not variations at the hillslope scale. Copyright © 2004 John Wiley & Sons, Ltd.

**KEY WORDS** remote sensing; soil moisture; active microwave; synthetic aperture radar; backscattering; backscattering models; soil roughness; ERS-2

### INTRODUCTION

Recent advances in remote sensing have demonstrated the ability to measure the spatial variation of soil moisture content in the near-surface layer under a variety of topographic and land cover conditions using both active and passive microwave measurements. However, one important difference between spaceborne active and passive microwave remote sensing systems is the resolution of the resulting data. Active sensors have the capability to provide high spatial resolution, in the order of tens of metres, but are more sensitive to surface roughness, topographic features and vegetation than passive systems, meaning that soil moisture inversion from a single frequency, single polarization backscattering observation is difficult. On the other hand, the spaceborne passive systems can provide spatial resolutions only of the order of tens of kilometres, but with a higher temporal resolution.

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Most reviews suggest that near-surface soil moisture can be retrieved with sufficient accuracy from a multichannel (i.e. multiple frequencies or polarizations) synthetic aperture radar (SAR) instrument (e.g. Bindlish and Barros, 2000). However, all current spaceborne SAR instruments are single polarization, single frequency systems. To overcome this limitation, researchers have resorted to multiple images through time (e.g. Verhoest *et al.*, 1998; Moran *et al.*, 2000). This paper explores the potential to measure the moisture content of a near-surface soil layer using a minimum number of images from the single channel C-band SAR instrument on board the second European remote sensing (ERS-2) satellite. The ERS-2 backscattering measurements are compared with the predicted backscattering from several widely accepted state-of-the-art backscattering models (Fung *et al.*, 1992; Oh *et al.*, 1992, 1994) that are valid for the ERS-2 sensor configuration and roughness conditions of the field data. In addition to comparing measured and modelled backscattering values, and intercomparing the various backscattering models, this paper explores the potential for retrieving surface roughness parameters from simultaneous measurements of soil moisture and backscattering, and then using the retrieved surface roughness in future predictions of backscattering.

### BACKGROUND TO ACTIVE MICROWAVE REMOTE SENSING

The fundamental basis of microwave remote sensing for soil moisture content is the contrast in dielectric properties of water and dry soil, and the relationship between the Fresnel reflection coefficient and dielectric constant. For a land surface, the target consists of the interface between air and soil. As the dielectric constant of the air is a known value, the reflection coefficient provides a measurement of the dielectric constant of the soil medium (Jackson *et al.*, 1996).

As the scattering behaviour of a surface is governed by its geometrical and dielectric properties relative to the incident radiation, the variations in backscattering are influenced by soil moisture content (through the dielectric constant), topography, vegetation cover, surface roughness, observation frequency, wave polarization and incidence angle. A variation of relative dielectric constant between 3 and 30 (a shift in volumetric moisture content between approximately 2.5% and 50%, depending on frequency and soil texture) causes an 8 to 9 dB rise in backscatter coefficient for  $vv$  (vertical transmit vertical receive) polarization (Hoebein *et al.*, 1997). This change in backscattering is almost independent of other parameters, such as incidence angle, frequency and surface roughness, but the total amount of backscattering is affected. The relationship between backscattering coefficient and dielectric constant is non-linear, having a higher sensitivity at low dielectric values.

### CONCLUSIONS

It was found that even when using the same input data there was a large variation in backscattering estimates from the three state-of-the-art backscattering models tested, with a RMS difference as large as 3.7 dB and  $r^2$  as low as 0.53. Moreover, it was found that when using measurements of near-surface soil moisture and roughness from a 6 ha experimental catchment as input to these backscattering models, there were significant RMS errors (up to 8.4 dB) and negligible  $r^2$  values (less than 0.1) when comparing the model output of backscattering with ERS-2 SAR observations. Spatial filtering of the ERS-2 SAR data had the effect of both increasing the  $r^2$  (up to 0.25) and decreasing the RMS values (by up to 1.3 dB). Using model output of near-surface soil moisture (1 cm) in place of the measured near-surface soil moisture (15 cm) reduced the RMS errors slightly (by up to 2 dB) but did not improve the  $r^2$  values. Using the first day of ERS-2 SAR observations and measured/model soil moisture to solve for the RMS surface roughness reduced the RMS errors for the second day to between 0.9 and 1.3 dB (when using a  $3 \times 3$  filter) but made only marginal, if any, improvement to the  $r^2$  values.

These results suggest that more work is required to improve the agreement between backscattering models. Furthermore, providing a site-specific surface roughness was calibrated then all models could satisfactorily predict the level of ERS-2 SAR backscatter, but not its spatial variation within a hillslope. Without calibration none of the models provided satisfactory predictions of backscatter level. Moreover, spatial filtering of 'speckle' in the ERS-2 data increased the  $r^2$  values slightly, suggesting that ERS-2 backscatter data does not contain soil moisture information at less than the field scale. A similar conclusion was reached by Western *et al.* (submitted) in their study with AirSAR data. Thus, ERS-2 SAR backscatter data may provide field-scale soil moisture estimates but only with appropriate filtering and calibration of surface roughness parameters.